Warsaw University of Technology
EURATOM-IPPLM Association

24th Symposium on Fusion Technology

11 - 15 September 2006 - Palace of Culture and Science, Warsaw, Poland

24th SOFT 2006

TOPIC: D - Diagnostics, Data Acquisition and Remote Participation
(P1-D-399)

Diamagnetic loop measurements in JT-60U with precision analog integrator

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It is indispensable to evaluate the plasma stored energy accurately in order to investigate energy confinement properties. Although a method based on plasma diamagnetism has difficulties in attaining satisfactory accuracy, it enable us to directly measure the time evolution of the stored energy in every shot. Diamagnetic loops were wound inside the vacuum vessel of JT-60U. The vacuum toroidal flux is compensated by the use of a loop pair with slightly different pick-up areas instead of a Rogowski coil previously adopted for JT-60. The best set with least errors among four sets of diamagnetic loops has been used for routine diamagnetic measurement. The main loop (four turns) and the compensation loop (three turns) are located along a vessel connecting ring to be rigid enough to minimize the variation of the toroidal field coupling. The main and compensating loops are separated by 31±1 mm in the radial direction. The toroidal fluxes through the main and compensating loops in the case of It = 52.1 KA (Bt = 4.0 T at R = 3.32 m) are ?tm = 96.9 Vs and ?tc = 76.5 Vs, respectively. Differential integration is made with a precision analog circuit with a potentiometer for the adjustment. Automatic cancellation of input offset voltage is implemented to achieve very low drift. The maximum pulse length of a discharge in JT-60U was extended from 15 s to 65 s in 2003. The excitation of the toroidal magnetic field coils begins 30 s ahead of plasma breakdown so that the integration time is longer than 95 s. With increased electrostatic capacity of a cancellation capacitor, the equivalent input offset voltage is less than 1 ?V even with an input offset voltage higher than 1 mV.

The stray couplings of the loops with poloidal magnetic fields are removed by digital post-processing. The plasma stored energy is calculated by surface integrations with a fast boundary identification code which approximates the plasma current as six filaments or a code based on the Cauchy-condition surface method. The residual error arising from the direct coupling to the plasma current were determined experimentally by sweeping the plasma column vertically or horizontally during low density discharges and by making computed plasma stored energy not to be so positionally sensitive nor to be negative in extremely shifted cases. The absolute error in the diamagnetically measured plasma stored energy [MJ] is estimated to be not more than 0.10_ Ip [MA] by comparison with the kinetic stored energy.